Experience with and expectations for the drive laser for the APS PC gun

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Layout

* **Current APS drive laser**
  - Configuration, and features
  - Problems and solutions
  - Current performances, and surprises
  - Summary

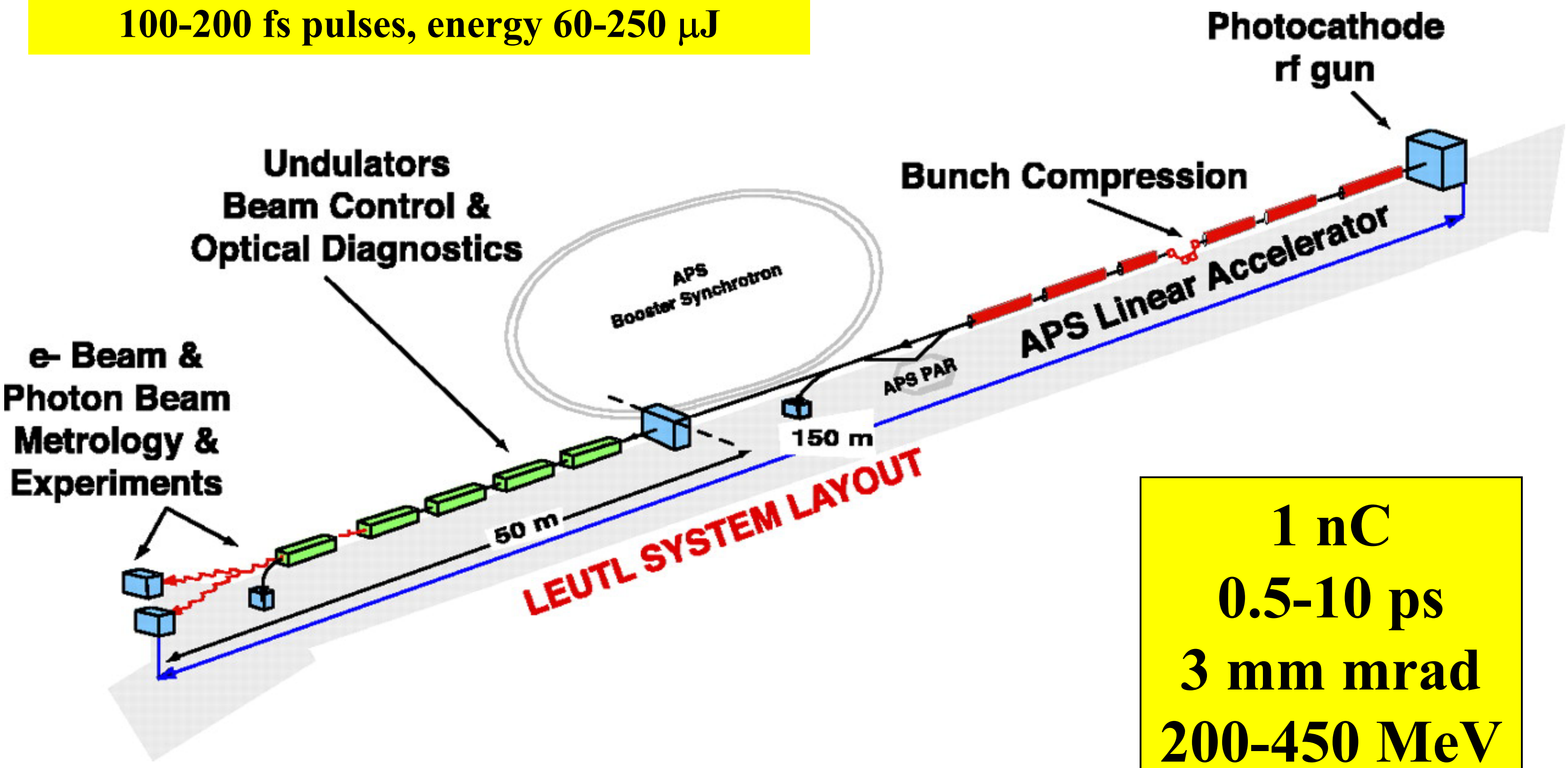
* **Expectation for the next drive laser**
  - Operation and performance requirement
  - Some commercial systems, new ideas
  - Adaptive emittance optimization loop
  - Summary

* **Acknowledgement**

Role of the APS pc gun drive laser

LEUTL: the free electron laser project

Saturated at wavelength as short as 150 nm
100-200 fs pulses, energy 60-250 μJ



1 nC
0.5-10 ps
3 mm mrad
200-450 MeV

APS pc gun drive laser

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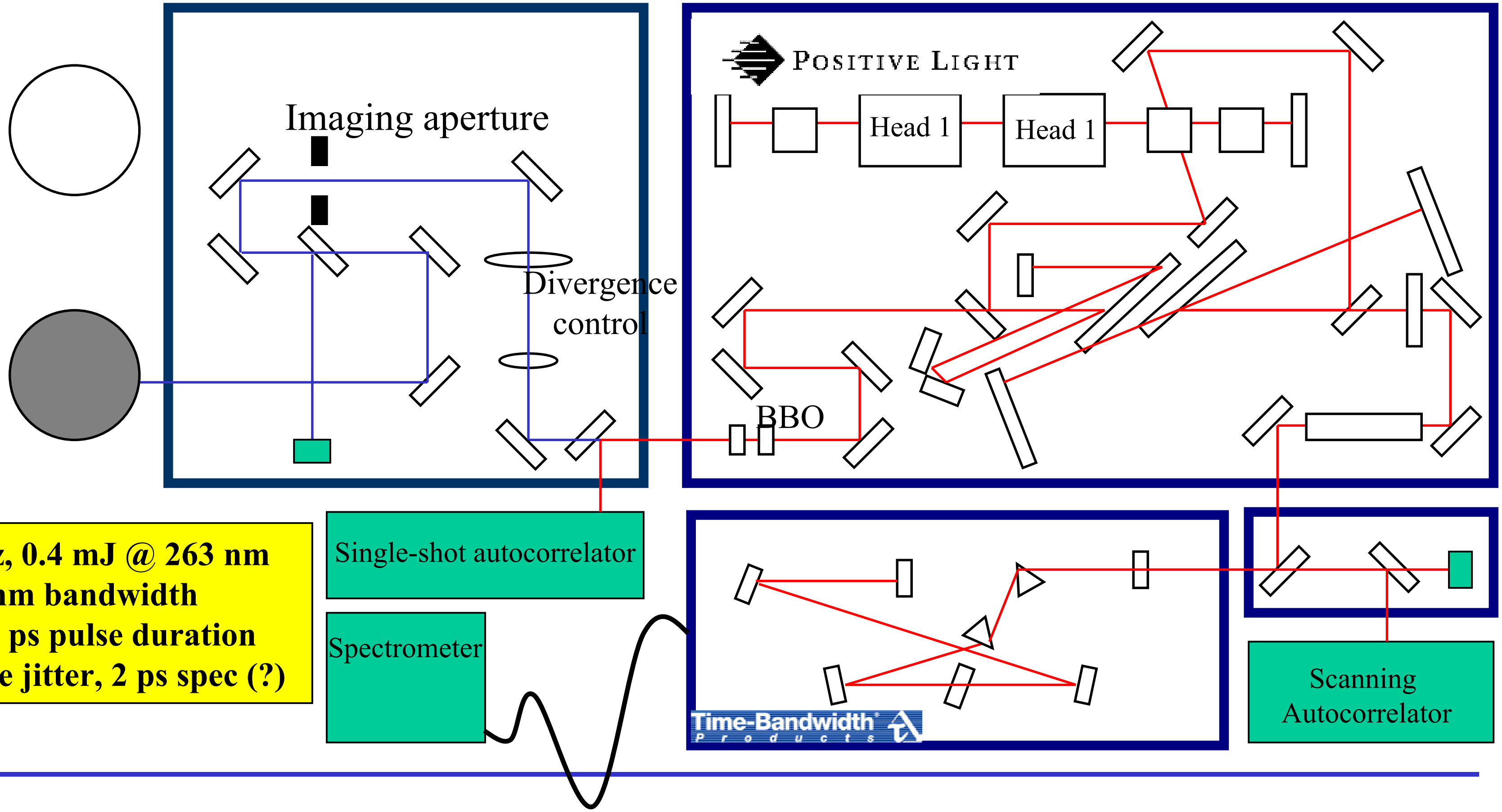
Flash lamp-pumped Nd:Glass
Chirped pulse amplification laser



6 Hz, 0.4 mJ @ 263 nm
1.8 nm bandwidth
1-10 ps pulse duration
Time jitter, 2 ps spec (?)

Features

Environment Monitoring

- Temperature and humidity

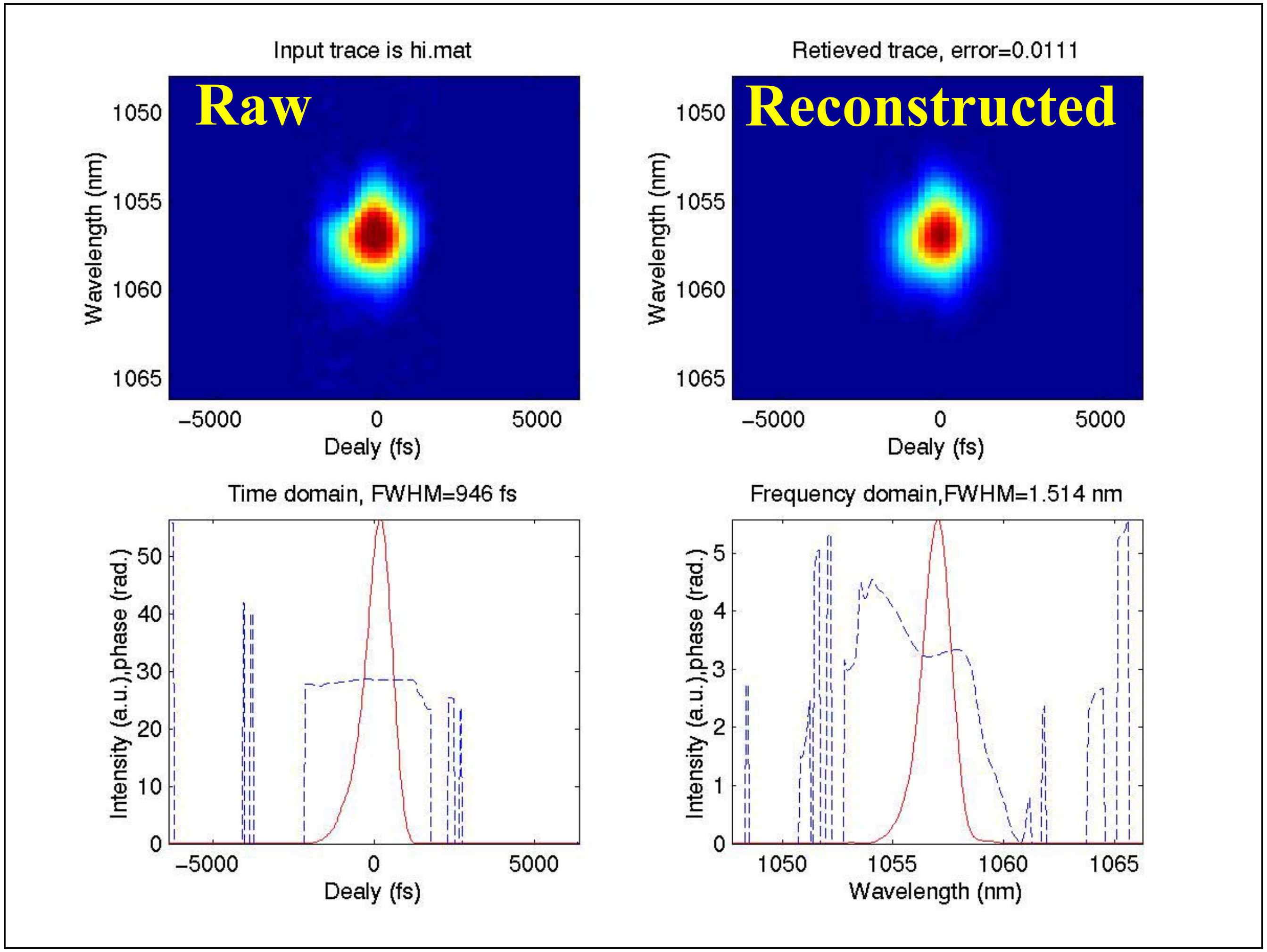
Laser monitoring

- Oscillator
  - Energy (off line), pulse duration (off line), mode, spectrum,
- Amplifier
  - Cavity buildup, mode, pulse duration, FROG (offline)
- UV
  - Energy, mode, virtual cathode

Laser control

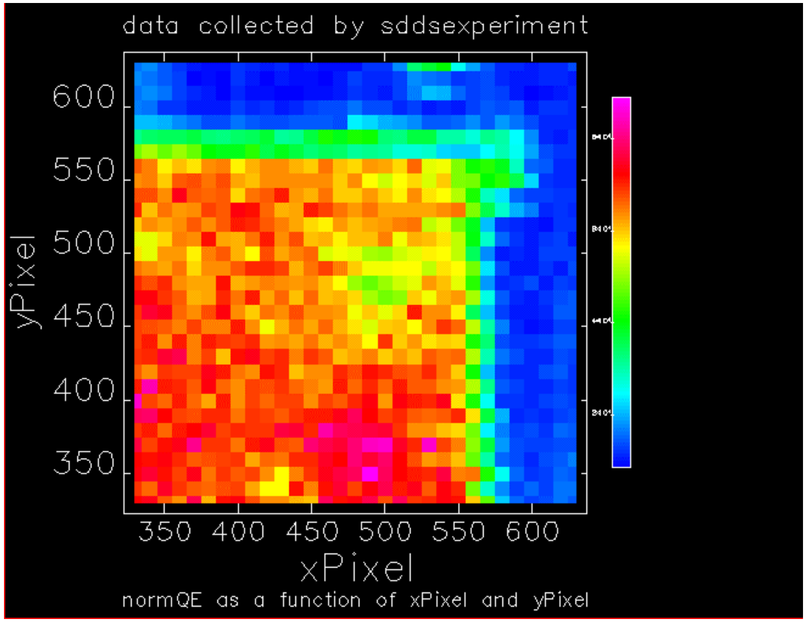
- Off line: Pulse duration, divergence, spot size on VC
- On line: Pulse energy, trajectory
- Semi automatic cathode cleaning

FROG traces of the laser

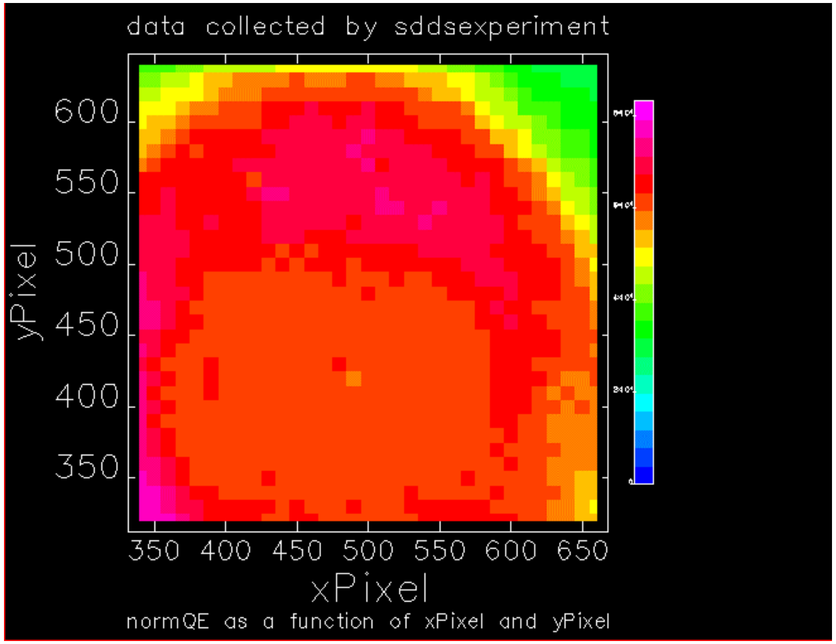


Semi automatic cathode cleaning

Before



After



Problems and solutions

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Poor beam profile

mode inhomogenity
higher order mode

- Replacing KDP with BBO
- Adding pinholes at both end of the cavity
- Sealing the transport line
- Imaging

Poor pointing stability

50% rms

- Imaging
- Sealing the transport line

Poor output

up to 50% rms
not enough energy

- Replacing stretcher-compressor gratings
(From originally unknown 1800 l/mm, 76% efficiency to JY 1740 l/mm, 90% efficiency)
- Scheduling flash lamp replacement
- Switching cathode from Cu to Mg

Poor reliability

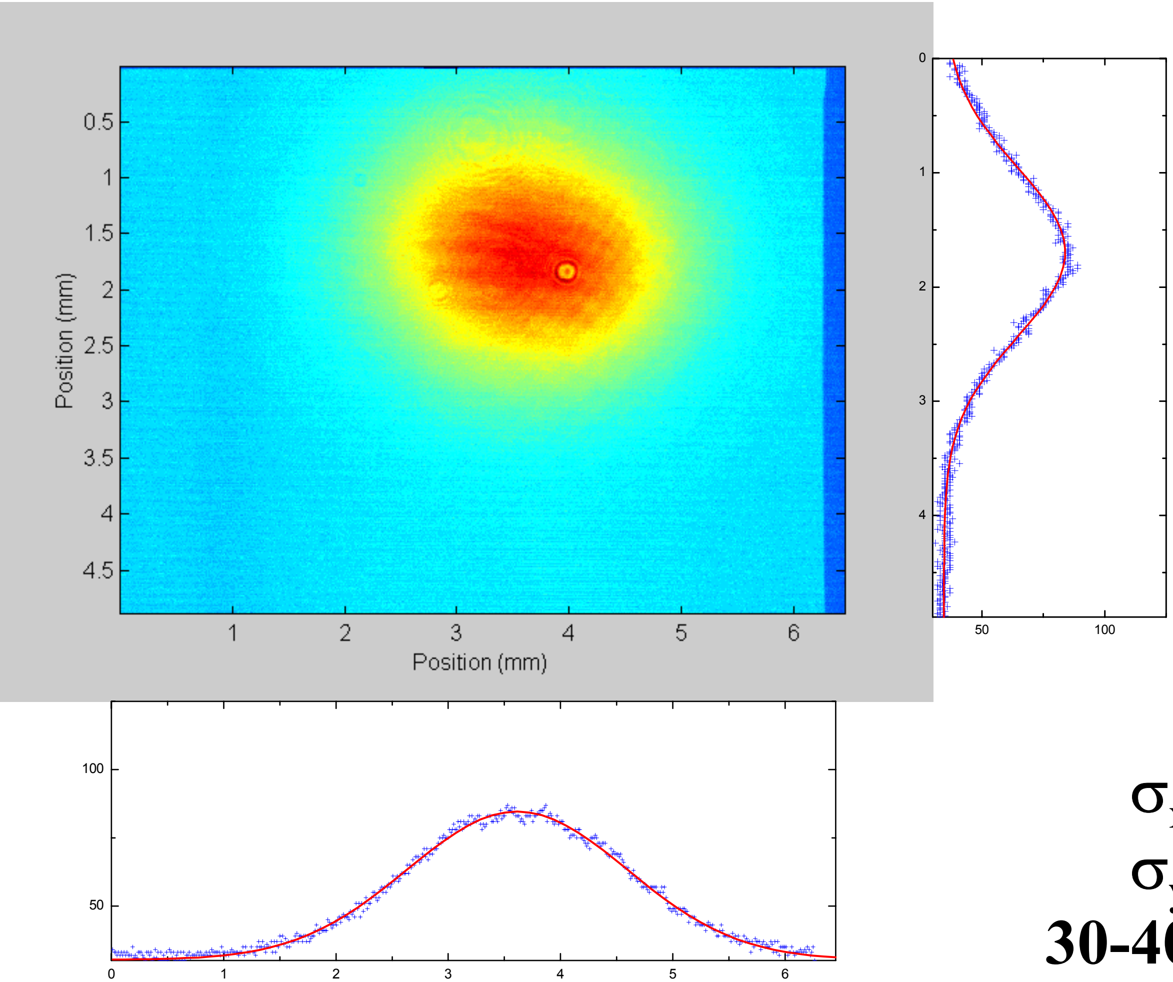
mechanical broken rods
optical damage

- Switching Kigre rods to Schott rods
- Adding pinholes to cavity

Intense maintenance

- Hiring a baby sitter

IR Spatial Profile

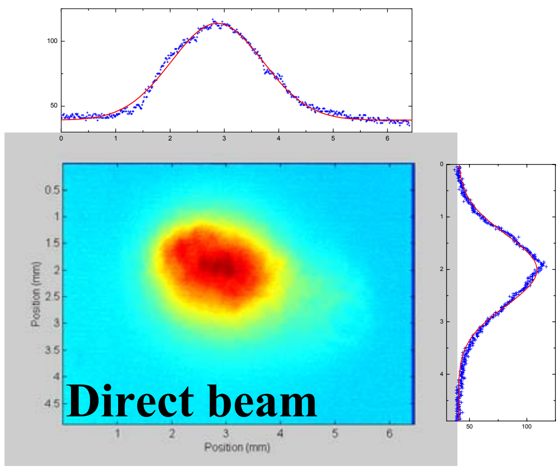


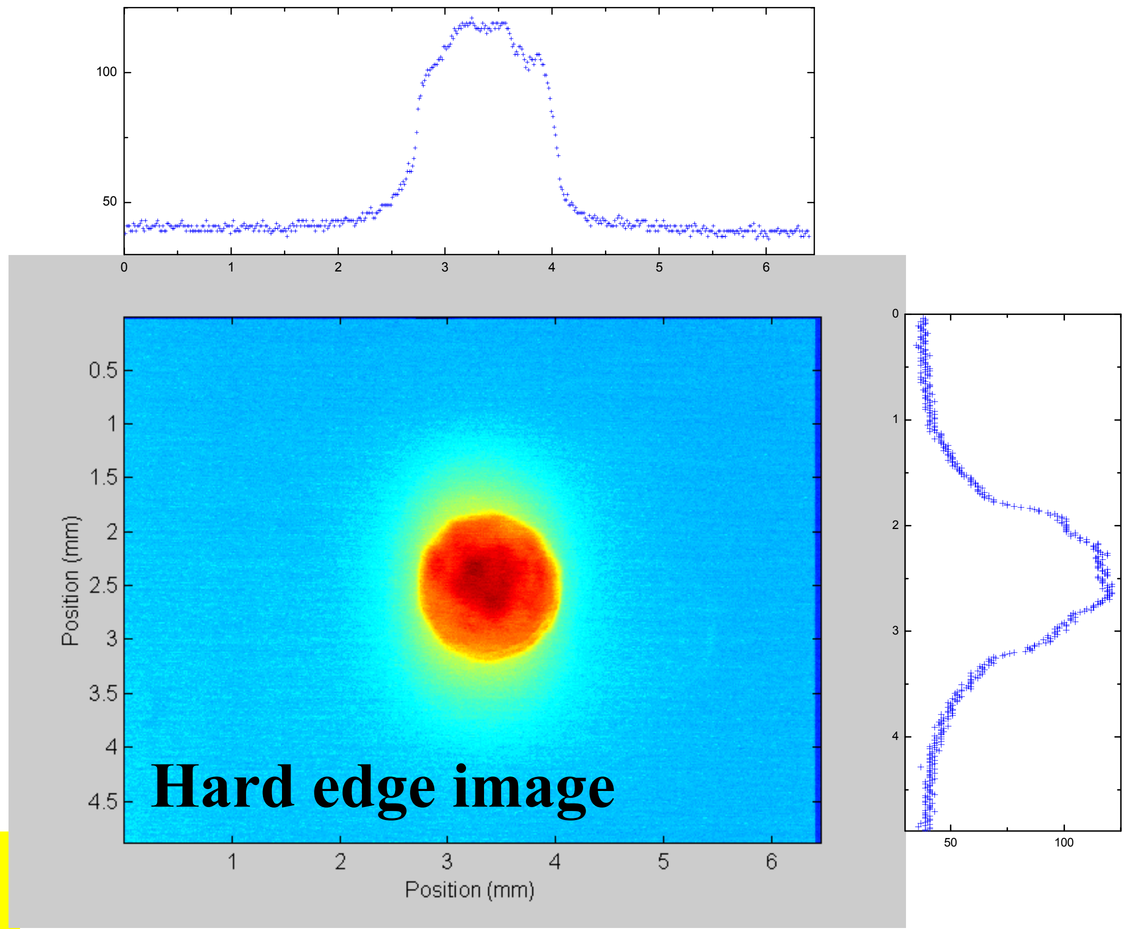
σ_x=1.14 mm

σ_y=0.79 mm

30-40 mW @ 6 Hz

Virtual cathode images





Size:	variable
Profile:	30% flat top
Pointing stability:	~2%

Frequency conversion

The power in the second harmonics at matched phase is (with pump depletion)

$$\frac{P_{2\omega}}{P_{\omega}} = \tanh^2\left(\frac{L}{L_{NL}}\right)$$

$$L_{NL} = \frac{1}{4\pi d_{eff}}\sqrt{\frac{2\varepsilon_0 n_{\omega}^2 n_{2\omega} c\lambda_{\omega}^2}{I_{\omega}}}$$

For BBO, type I critical phase match

	λ_{ω} (μm)	n_{ω}	$n_{2\omega}$	d_{eff} (pm/v)
SHG	1.053	1.6551	1.6551	1.9
FHG	0.527	1.6749	1.6749	2.0

$$L_{NL2\omega} = \frac{6913}{(P_{\omega}/A)^{1/2}}$$

$$L_{NL4\omega} = \frac{3443}{(P_{\omega}/A)^{1/2}}$$

$\rightarrow$

At low intensity

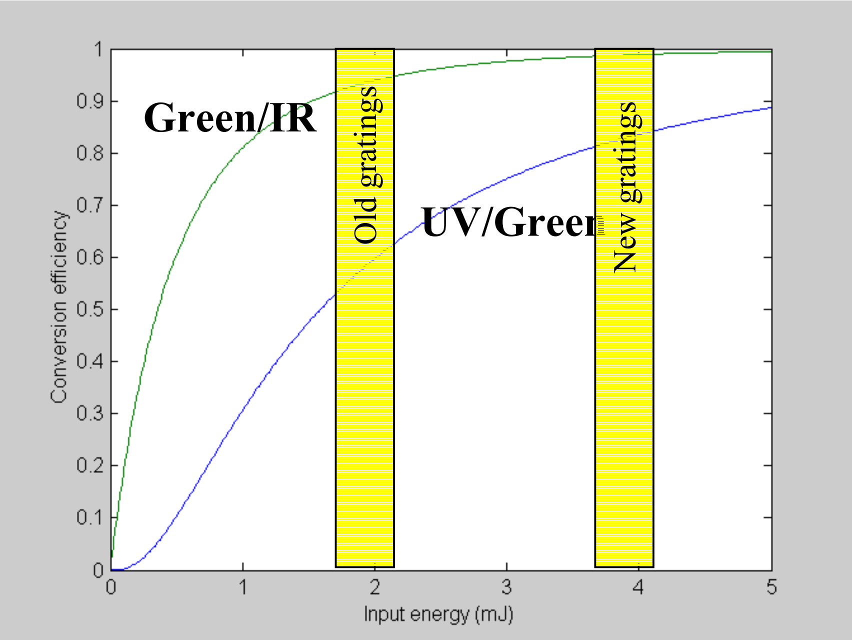
$P_{4\omega} \propto P_{\omega}^4$

At high intensity

$P_{4\omega} \propto P_{\omega}$

Frequency conversion

Expected Conversion efficiency



Measured

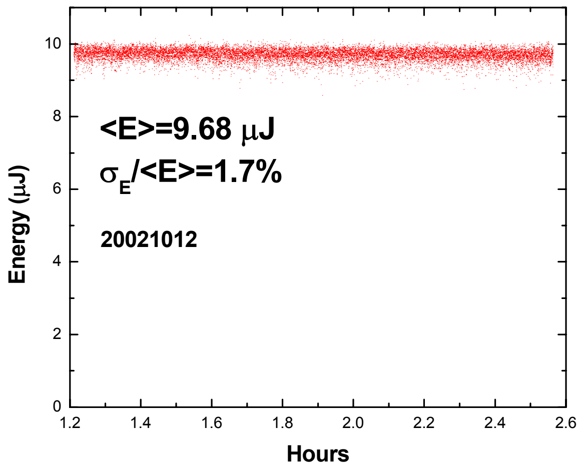
Green/IR	53%
UV/green	20%

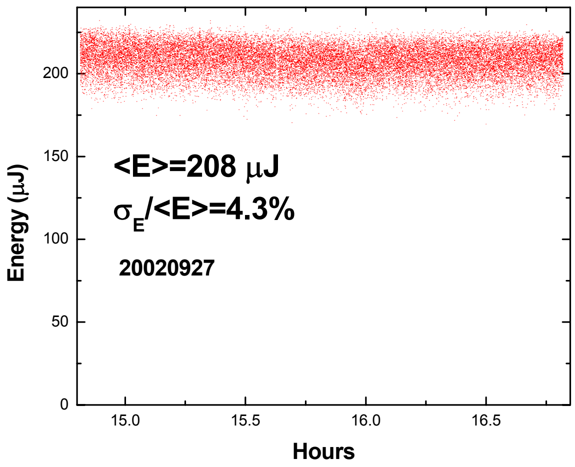
	1.064 μm	0.532 μm
Angular acceptance (mrad cm)	0.53	0.16
Temperature bandwidth (K cm)	51	4.0
Wavelength bandwidth (nm cm)	2	0.073

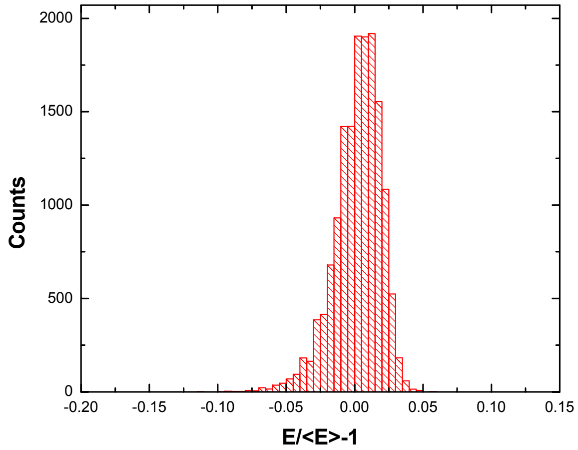
UV Energy stability

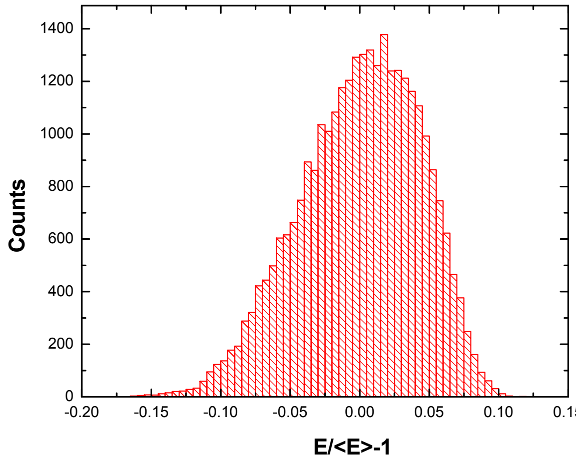
Lamps at 1 million shots

Lamps at 10 million shots





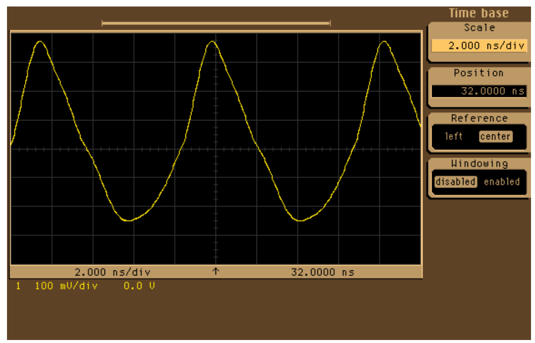




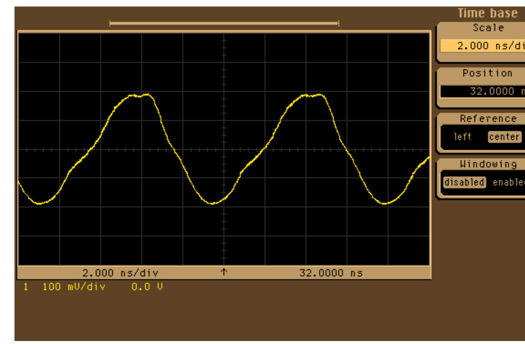
Surprise: Timing stability

Laser oscillator TBWP GLX-200 oscillator at 119 MHz
Lock device TBWP CLX-1000 timing stabilizer with spec <2 ps
RF source Gigatronics 2856 MHz/24 orCrystal oscillator 119 MHz

119 MHz rf waveform

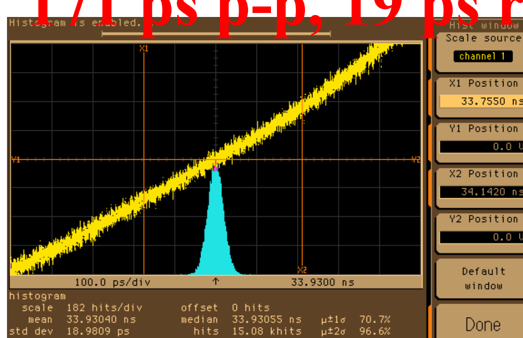


Laser rf waveform



Laser rising edge

171 ps p-p, 19 ps rms



Laser falling edge

56 ps p-p, 7 ps rms

Summary on current laser

* **Finally usable in stability and profile**

However: it is stretching its limit ….

* **Flash lamps age quickly**

  10 million shots is the margin we use now
  3-weeks of 24-7 operation at 6 Hz
  Needs careful attention for stable operation at the end

* **Laser rods break at about 15 million shots or less**

  Time consuming
  Changes laser characteristics: divergence, mode size, optical path, etc….

- **No room for further improvement**
  Energy stability, reliability, etc..

Time to dream for a new drive laser

The future APS drive laser

Role

Primary electron beam source for both LEUTL and APS in routine operation (LEUTL is becoming a user facility)

Key operational requirement

Turn key system
Reliable: no break down during normal operation
Stable over long time
Minimum maintenance
Deliver up to 5 nC per shot for injection to APS

The role of cathodes

Cathode	$(E_{gap} + E_A)$/eV	Q.E. (263nm)	Life	Laser energy/nC
Cu	4.5-5.6 eV	2×10^{-6} (APS) 3×10^{-5} (Nguyen, LANL) 4×10^{-5} (GTF)	Long	2.4 mJ 160 μJ 120 μJ
Mg	3.78 eV	1.3×10^{-4} (Spring-8) 1.3×10^{-3} (APS) 3×10^{-3} (Nguyen, LANL)	Long	36 μJ 3.6 μJ 1.6 μJ
Cs_2Te	3.5 eV	5% (Nguyen, LANL) 1% (FNAL)	Months	
CsI	6.4 eV	Est. 10^{-3}	Long	
K_2CsSb	2.1 eV	10%	Hours	
Cs_3Sb	2.05 eV	6%	Unstable	

Laser: Dream vs reality

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	Current	Dream	Reality
Pulse energy on cathode [a]	<500 μJ	100 μJ	☺
Pulse repetition rate [b]	6 Hz	60 Hz	☺
Energy stability	2% rms	0.5% rms	☺
	5-10% p-p	2% p-p	☺
Pulse length	2-10 ps	2-10 ps	☺
Pulse shaping	Possible	Y	😐 R&D needed
Profile shaping	Semi	Y	😐 R&D needed
Spatial homogeneity	50%	10%	😐 R&D needed
Pointing stability	1-5% rms	1% p-p	☺ R&D needed
Timing jitter to rf	6 ps rms (2 ps spec)	<0.5 ps	😐 Demonstrated
Advanced features			
Active hydrothermal control	N	Y	☺
Automatic energy control	Possible	Y	☺
Automatic emittance optimization	N	YYY	😐 R&D needed

a. Based on APS QE for a Mg cathode of about 1.3×10^{-3}, for 1 nC of charge from the gun.

b. With long life cathode, single pulse per rf cycle. For a SC rf with higher duty factor the requirement is different.

Commercial Ti:Sa amplifier systems

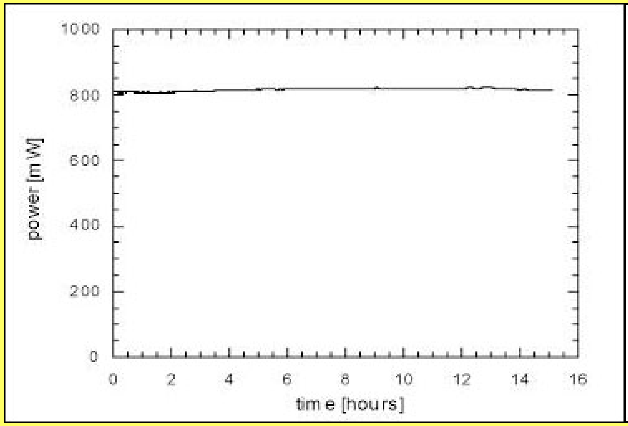
Advertised performances

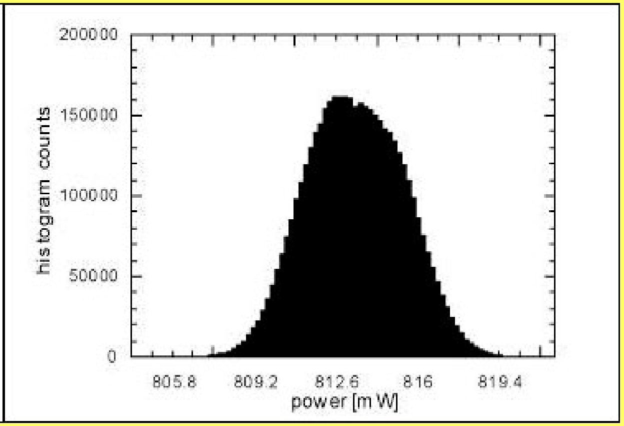
Make and model	Rep rate	Energy	Stability	Mode
Clark MXR, CPA-2010	0.2-2 kHz,	>0.6 mJ,	1%	TM00
	(Built in active hydrothermal Stabilization)			
Spectra Physics, Spitfire	1-5 KHz	0.7 mJ	1% (p-p)	TM00, 1.5 diffraction limit
Spectra Physics, Hurricane	1-5 KHz	0.7 mJ	1.5% (p-p)	TM00, 1.5 diffraction limit
Femto Lasers, FemtoPower	1 kHz	0.8 mJ	2% (p-p)	TM00, 2 diffraction limit
Coherent RegA9000	300 kHz	4 µJ	2% (p-p)	TM00, 2 diffraction limit

Performance Example

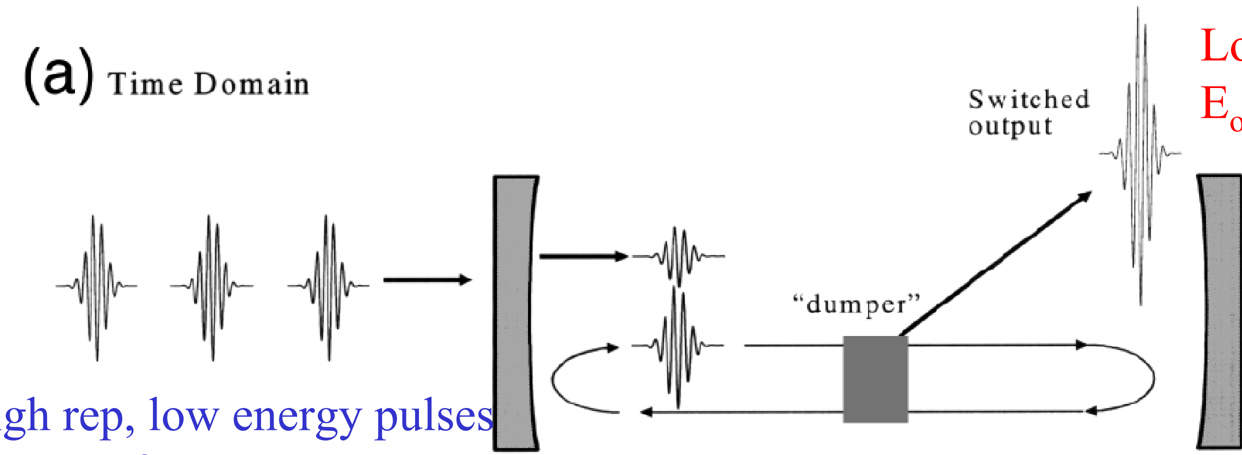
Spectra Physics-Positive Light Hurricane

Energy stability <1.5% p-p, 0.24% rms @ 1k Hz (http://www.poslight.com/)





An idea: Gain less amplifier



Low rep output
$E_{out}=nE_s=E_s/loss$

Seed: high rep, low energy pulses
f, E_s

Cavity with length matching the rep rate of the seed, $L=1/f$

Example: 300 mW, 100 MHz, for loss=10^{-4}, E_{out}=30 μJ @100 kHz

Advantages

Ultra stable:	**$E_{out}=n\langle E_s\rangle$**
Linear device:	**easier to shape**
Low jitter:	**no jitter between seed and output**

Jones and Ye, Opt Lett 27, 1848 (2002)

Commercial lockable oscillators

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Advertised performance

Make and model	rep rate	jitter spec
TBWP TIGER 200/CLX1100	up to 150 MHz	<1 ps
Femto Laser Femto Source/Femtolock	up to 150 MHz	<1 ps
Spectra-Physics Lok-to-Clock Tsunami	up to 100 MHz	<1 ps
Coherent Mir Synchro-Lock	up to 100 MHz	<2 ps

Laser	TBWP TIGER 200 oscillator at 119 MHz
Locking	TBWP CLX1100
RF source	HP 8665B at 119 MHz

Test results 8 ps

"Subfemtosecond timing jitter between two independent, actively synchronized, mode locked lasers"
Shelton et al, Opt Lett 27, 312 (2002)

Adaptive pulse manipulation

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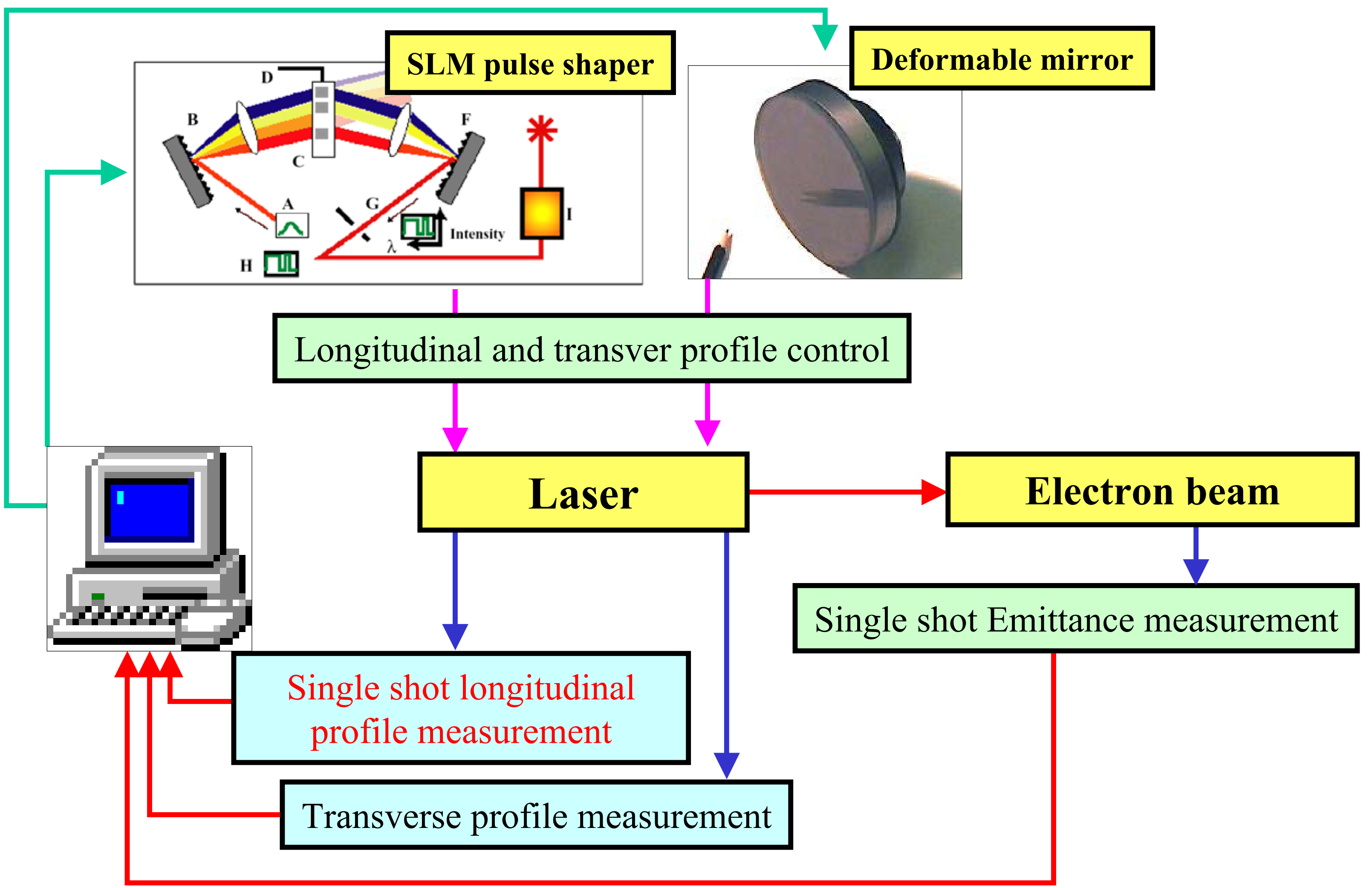


Measurement techniques

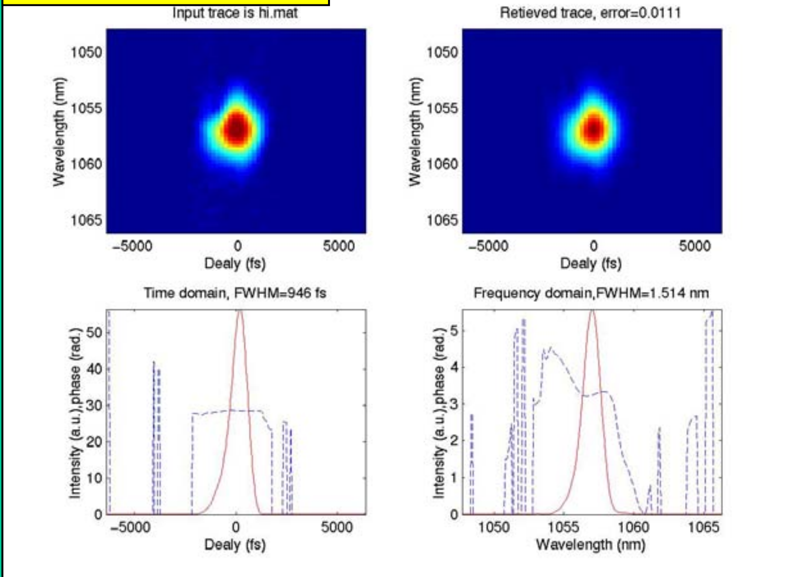
Laser longitudinal profile

FROG is the choice

in IR, green, SHG

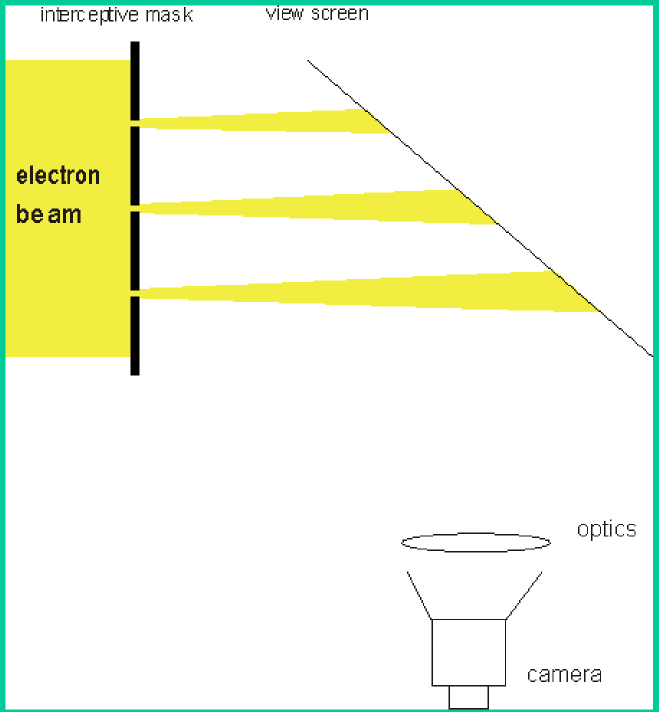
in UV, Polarization gating

FROG example



Single-shot emittance measurement

Multi slit mask



Summary

Laser

Laser technology is mature enough for the basic requirement

Advanced features

R&D is needed to adapt existing adaptive pulse shaping and waveform control technologies

Acknowledgement

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